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Maximum power point optimization for a grid synchronized PV system considering partial shaded condition using multi-objective function

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ABSTRACT

Energy demand taking a bigger leap day by day, Renewable energy gets the most leading importance in catering the purpose. Solar being the abundantly available renewable energy resource solar panels are key components in harnessing solar energy. Solar energy is the most dependable and cheap energy in renewable sector. But harnessing solar energy with partial shading makes it difficult for simple tracking algorithm because of multiple power peak points. Settling time of DC link voltage during the dynamics in the load and the irradiation also plays a major role in power delivered to the grid. Highly dynamic situation aware processors have been in the verge for many applications where large amount of online processing is a need like the smart grid, which needs a faster online reacting time. This paper deals with such an online reacting Maximum Power Point Optimization (MPPO) on a PV system with Partial shaded condition (PSC). The MPPO uses the recent non-parametric optimization techniques like Particle Swarm Optimization (PSO) for maximizing the power delivered from the solar panel. This optimization is achieved by populating the duty cycle and Kp and Ki parameters of PI controller given to the DC-DC converter connected to the PV arrays for the stable supply to the grid. While applying the maximization algorithm for the solar power output from the PV arrays the PSC conditions are considered in order to make the control technique more robust. This paper deals with minimization of DC link voltage settling time and maximization of power in multi-objective. MATLAB based simulation is carried and the comparative inference is produced in this paper. The simulation is developed for the 2.5kW PV array with the proposed method. The simulation carried out had performed better with the proposed method than the single objective method.Satisfactory results were observed both in the simulation of the proposed algorithm.

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1. INTRODUCTION

Dynamic conditions and higher reaction time has become the need of the hour in every application in the electrical domain since the loss of power would affect the overall carbon imprint from the usage. The Maximum Power Point Tracking (MPPT) techniques are those which are the cause of the dynamic

adjustment of the power supplied either to the batteries or to the Grid. Solar based supplies would reduce largely the carbon imprint and the newer MPPT algorithms would help in those conditions which needs higher reaction time and dynamic reaction. The partial shaded condition introduces lot of dynamics into the system in terms of the power and voltage variations delivered from the PV array [1]. In this paper the dynamics are controlled by applying the Fuzzy logic based MPPT technique, which would concentrate on the “Global Maximum Power Point (GMPP)”, defined as the maximum power including the partial shaded conditions are introduced. It has been discussed in the literature [2] that the PSC would introduce dynamics in the P-V characteristics of the PV array, which may lead to multiple MPPs while applying the conventional MPP methods. Due to the constrained control of the traditional MPP methods only the local MPP would be attained and thus it settles down at that point. The GMPP would be missed due to the system specific traditional MPPT controllers. Among the literature [2] is one of them which proposes that the optimization techniques like the Flashing Fireflies, PSO and improved PSO would act as a generalized MPPT algorithm with the objective function of power delivered from the solar arrays. Power maximization from solar has been tapped from these algorithms. In order to provide an artificial intelligence to the MPPT algorithms

Artificial Neural Network (ANN) has been introduced in the incremental conductance method, which would be faster [3]. Differential Evolution based optimization of MPPT algorithm is discussed and compared with the conventional techniques [4]. Partial Shading Conditions would introduce multiple peaks on the P-V characteristics of the PV systems. The MPP of the load while the converter efficiency is calculated is different from that of the MPP of the PV systems [5]. The techniques discussed so far would blind scan the GMPP while wasting some energy without sensing whether the partial shading has occurred or not. Thus, in order to find the GMPP more efficiently and also to find whether the PSC has occurred or not a new improved MPPT algorithm is introduced in [6]. The method discussed in [6] would quickly find the GMPP by predicting the “Local Maximum Power Point (LMPP)” which occurs during PSC and the GMPP, instead of blind scanning. The power peak prediction of the PV arrays, by using the PV array models including different irradiance condition and temperature for series-parallel, bridge-linked and “total-cross-tied configurations” are predicted and validated with the commercial PV models [7]. Random Search Method (RSM) is based on the random number to finding the global maximum in any optimization problem.

The GMPP prediction is carried out on a PV array with PSC with RSM as the optimization technique and compared with PSO based GMPP prediction and two-stage “Perturb and Observe” (P&O) method. The low memory usage and the improved performance of tracking during different shading patterns projected the effectiveness of RSM [8]. The energy recovery method to recover the energy that get wasted during the PSC by harvesting the currents from the unshaded PV cells using power electronics switches for diverting the current and using inductors for storing the current temporarily is developed [9]. The reduction in the overall power due to the PSC on the series connected PV arrays is due to the reduced current flowing in most shaded module, which is maximized by the use of “distributed Maximum Power Point Tracking” (DMPPT) for each module [10]. The DMPPT uses the converter, which resonates the PV module using a shunt connected fly back converter by changing the secondary diode in the flyback converter. The converter would operate in both “resonant MPPT mode and normal flyback mode”, while it tracks exactly the maximum power point [10]. A Simulated Annealing based GMPPT implementation on PSC PV array is carried out [11]. Comparative analysis and enhanced GMMPT techniques are discussed in detail [12-15].

This paper is developed with consideration that the power delivered to the load must be optimized rather than only finding the MPP in the MPPT algorithms. An optimization algorithm that maximizes the power supplied to the grid and minimizes the settling time of DC link voltage is developed. The simulation is carried out on a 2.5kW PV system which analyzed for the amount of power delivered to the load with PSO optimized Algorithm for single as well multi-objective problems. Section –II in the paper details the experimental setup, Section-III about the simulation logic, Section –IV discusses the Results and Discussions.

2. PARTIAL SHADED PV ARRAY WITH GRID SYNCHRONISATION

The multiobjective optimization algorithm is applied on a PV GMPP tracking while different PSC is seen on different panels used. Figure 1 shows the schematic arrangement of five solar panels and other necessary accessories (converter, inverter and controller) for tracking of maximum power points under partial shaded conditions. Simulation experiments were conducted using MATLAB software. The specifications of SPV panels are given in Table 1 and shading patterns used are provided in Table 2. The PSO implementation of the GMPP with single and multi objective is formulated with maximization of power delivery as the objective and combination of maximum power delivery with minimized settling time respectively. Section 3 defines the formulation of the multiobjective PSO implementation.

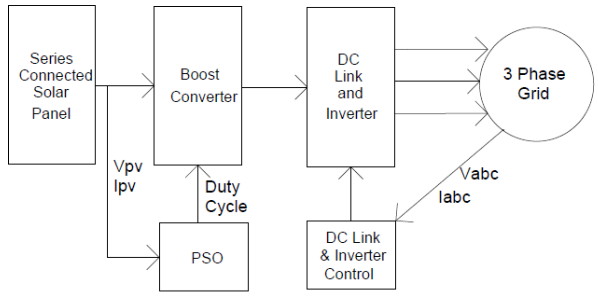

Figure 1. Block diagram of the system

Table 1. Electrical specification of the PV panel

Sl. No.	Item	Value
1	Open circuit VoltageVOC	22.099V
2	Short circuit ISC	8.36955A
3	Maximum voltage Vmp	17.7V
4	Maximum Power at STC Pmax	540W
5	Maximum system voltage	600V
6	Operating Temperature /Humidity	25

Table 2: Illumination details for shading patterns

	Shade pattern 1	Shade pattern 2	Shade pattern 3	Shade pattern 4
Panel 1	1000	1000	1000	700
Panel 2	1000	1000	700	700
Panel 3	1000	700	500	500
Panel 4	1000	700	300	500
Panel 5	1000	300	300	300

Several algorityhms are vailable for tracking maximum power points. However, the output also depends on settling time. Hence, in the present work, the circuit is designed for both (i) to track GMPP and (ii) to reduce settl;ing time of DC link voltage so that transfer of power to grid is maximized. The system is design is given in Table 3.

Table 3: Design of the system

Parameter	Detail
Power rating	2.5KW
DC link voltage	440 V
Inverter input and out put voltage	440 DC / 440V AC
Grid voltage	440V (ph-ph rms)
Grid frequency	50 Hz

3. THEORY

The parameter estimation of the PI controller is a prime concept that runs as the implementation's main theme. The parameter estimation intrinsically would solve the objective function which optimizes both the DC-link voltage settling time and inject or send the power to the utility grid/load. When it reaches its steady value the power transfer is initiated. So, the power transfer mainly depends on maximum power and settling time (ST). The PI controller parameters can be tuned manually or intuitively. For each duty cycle, the settling time varies due to instant variation of sampling time. To make it minimum at all the instant the optimization is included with multi objective. The settling time change can make the Steady State Error (SSE) zero more frequently. So, in each duty cycle change, the K_p& K_i parameters are also changed. The SSE of the DC link voltage can be represented as,

$$SSE = K_p\left(V_{dc\,ref} - V_{dc}\right) + \frac{K_i}{s}\left(V_{dc\,ref} - V_{dc}\right) \quad (1)$$

SSE – steady state error of the DC link regulation control,$V_{dc\ ref}$ - DC reference required,V_{dc} - DC measured,1/s - integral transfer function,K_p- proportional constant,K_i – Integral Constant

To make the selection of duty cycle, Kp and Ki parameters optimal the following multi-objective equation is used. Here settling time has to be minimized and power has to be maximized. So the $T_{set}$is inverted in the objective function. Maximize,

$$F\left(V_{ref}, K_p, K_i\right) = \frac{\sum_{i=1}^{n} P}{n} + \frac{1}{T_{set}} \quad (2)$$

Inequality Constraints

$$V_{ref\ min} \leq V_{ref} \leq V_{ref\ max}. \quad (3)$$
$$K_{p\ min} \leq K_p \leq K_{p\ max} \quad (4)$$
$$K_{i\ min} \leq K_i \leq K_{i\ max} \quad (5)$$

Here,
F – fitness function,Vref – reference voltage for MPP,K_p- proportional constant, K_i – Integral Constant,P – PV power,n – Sampling time count,T_{set} – settling time

3.1. PSO Implementation Details

Particle swarm optimization is the bioinspired algorithm based on the behavior of food search in birds. From a group of birds one bird locates the food or target and it instantaneously spreads the location to all other birds. All other birds follow the path of the food loaction from the current location the other bird had provided . Tracking of the food depends on the birds'independent thinking based on it past memory Proposed technique optimizes the result by tracking maximum power and reducing settling time using PSO algorithm.

Table 4: Converter Details

Parameter	Detail
Input Voltage	101V
Output Voltage	440V
Boost Converter Switching Frequency	10 Khz
Inductor	5mH
capacitor	6000 uC

Table5: Inverter design details

Parameter	Detail
Input Voltage	440 V
Output voltage	440 V
Frequency	50
Inverter voltage controlling technique	DQ technique

Boost converter duty cycle is controlled by the algoritum both power settling time(Tset) also taken in function. Hence DC link voltage settles faster and power also maximizes.

4. RESULTS AND DISCUSSIONS

Incremental conductance (IC) algorithm is initially used to track the maximum power. Later, PSO algorithm is adopted to track GMPP as well as to reduce settling time. The results from both algorithms are compared.Figure 4 -6 represent power transferred, DC link voltage and control error obtained for shade pattern 1 under single objective (with increased power delivery) and multi-objective (increased power delivery and reduced settling time). Figure 4 shows the power transferred to the grid in single objective and multi objective. Multi objective algorithm provides 2699W and single objective is 2590W. In this improvement of power transferred to grid can be observed. Figure 5 shows the settling time of DC link voltage (Tset). The power transferred to the grid , DC link voltage and tracking error or the controller error for all the four patterns decided in Table 2 is depicted from Figure 4 to Figure 15, pattern after pattern considered.

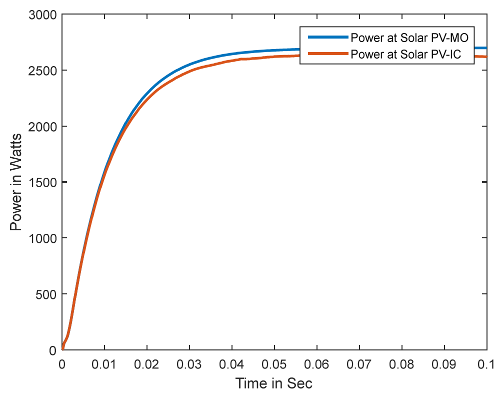

Figure 4. Pattern 1: Power transferred to Grid

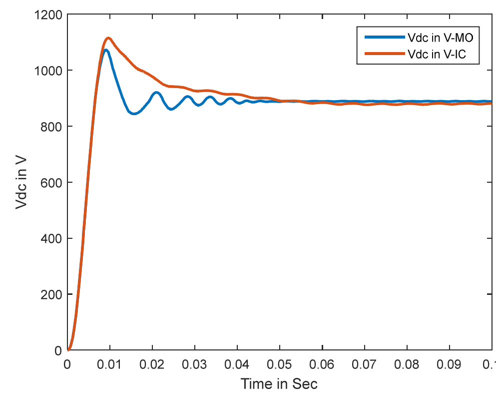

Figure 5 Pattern 1: DC link voltage

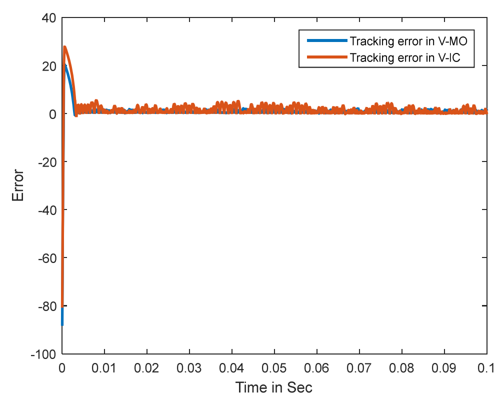

Figure 6. Pattern 1: Tracking error or controller error

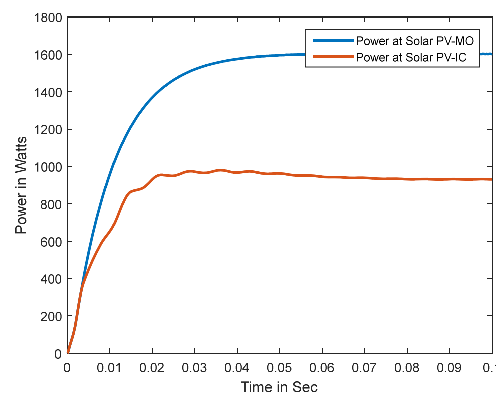

Figure 7. Pattern 2: Power transferred to Grid

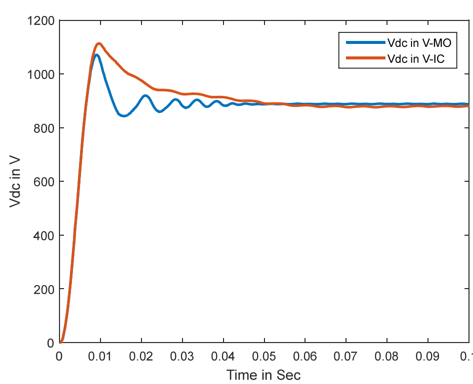

Figure 8. Pattern 2: Dc link voltage

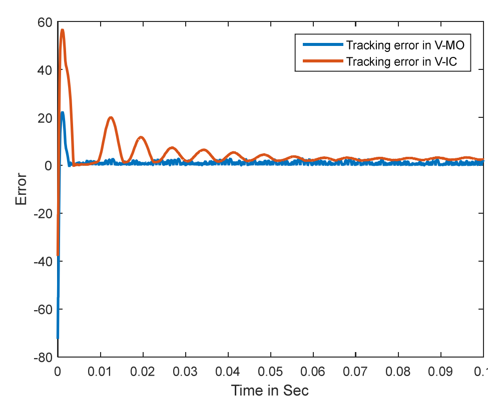

Figure 9. Pattern 2: Tracking error or controller error

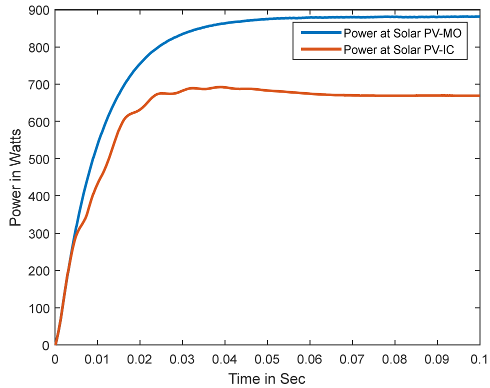

Figure 10. Pattern 3: Power transferred to Grid

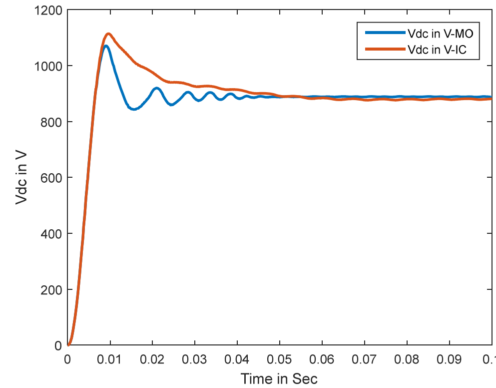

Figure 11. Pattern 3: Dc link voltage

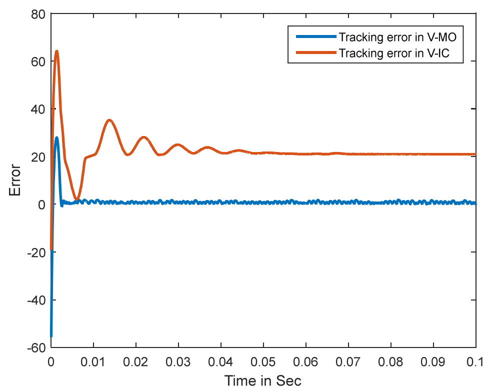

Figure 12. Pattern 3: Tracking error or controller error.

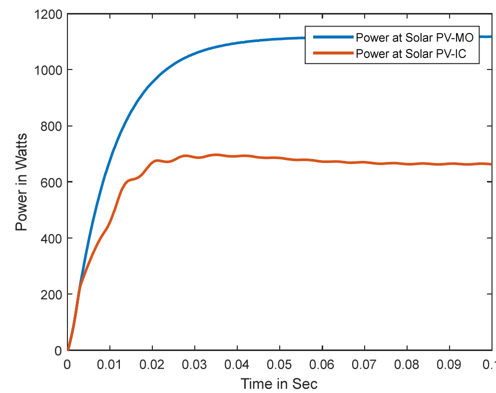

Figure 13. Pattern 4: Power transferred to grid

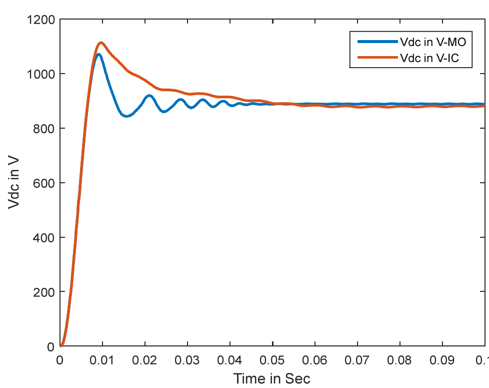

Figure 14 Pattern 4: DC link voltage

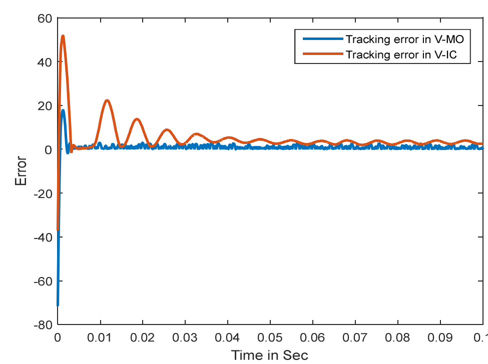

Figure 15 Pattern 4: Tracking error or controller error

Table 6. Comparison table

Pattern	Single objective			Multi objective		
	Power in W	Vref in V	VdcTset in S	Power in W	Vref in V	VdcTset in S
Pattern 1	2590	80.95	0.045	2699	88.5	0.023
Pattern 2	1153	39.6	0.045	1606	72.6	0.023
Pattern 3	710	38.6	0.045	1116	71.7	0.023
Pattern 4	750	38.7	0.045	880.5	55.6	0.023

The settling time of multi objective is 0.023sec and it is 50% less than single objective. Figure 6 shows the controller error both single and multi-objective .Similarly other graphs indicates similar behavior in other shade patterns can be observed The table 6 shows the comparison between multi objective and single objective this clearly show that the multi objective produces more power than the single objective . Shade pattern 1 shows 4% of increase in power but in partial shaded condition from pattern 2,3,4 the power is incresed significantly 28.21%, 36.38%, 14.82% respectively and 50% improvement in settling time.

5. CONCLUSION

Matlab based simulation is carried out and the results are inferred from a 2.5kW simulation. It is observed that there is an improvement in the power delivered when the partial shading conditions is included in the multiobjective optimization technique thus applied. The multiobjective optimization of the GMPP tracking in this paper has inferred improvement than that of the single objective optimization. The pattern 1, 2, 3, and 4 of shading had shown an improvement of 4%, 28.12%, 36.38% and 14.82% respectively while the multiobjective optimization is involved, than the single objective optimization algorithm thus validating the proposed algorithm.

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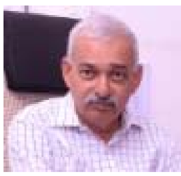

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